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SUBCARRIER-BASED SELECTION DIVERSITY RECEPTION OF DVB-T IN A MOBILE ENVIRONMENT

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Abstract — Some comparative results on simple diversity combining schemes are presented to be used with Orthogonal Frequency Division Multiplexing (OFDM) systems and especially in DVB-T in multipath channels with time selective fading. A comprehensive performance evaluation of these methods is given.

I. Introduction

To overcome the problems caused by multipath propagation in wireless systems, the use of Orthogonal Frequency Division Multiplexing (OFDM) scheme has been proposed. In this kind of scheme high rate data are transmitted in several narrowband low rate sub-channels, hence allowing to combat effectively against delay spread [1]. Attention to OFDM has increased with the standardization of OFDM for Digital Audio Broadcasting (DAB) [2] and Digital Video Broadcasting for terrestrial channels (DVB-T) [3,4]. The suitability of OFDM to mobile wireless systems has been studied extensively recently [5-7]. It has been turned out that OFDM is very interesting alternative to mobile systems when flexibility, scalability, and simple equalization schemes are required.

The mobile wireless channel is, in general, both time and frequency selective due to relative movement of receiver and transmitter, and because of multipath propagation. The time selectivity of the channel induces Inter Carrier Interference (ICI) to the signal, hence lowering the system performance. Correspondingly, the frequency selectivity of the channel generates Inter Symbol Interference (ISI). Fortunately, ISI can be eliminated by adding a cyclic extension or Guard Interval (GI) in front of the OFDM symbol [1]. The removal of ICI is much more complex task, which includes both very good knowledge of the channel response and reasonable knowledge of transmitted data. In the case of relatively fast fading channel, the ICI cancellation will become a tedious process.

Due to existing ICI, there will be an error floor where Bit Error Ratio (BER) saturates even when no additive channel noise is present. The saturation level of BER depends on Doppler frequency which characterizes the time selectivity of the channel. To improve the performance of OFDM system in channels with ICI, simple diversity reception schemes are suggested to be utilized. In the following such schemes are examined and compared.

II. OFDM System

In an OFDM system there are multiple orthogonal subcarriers that are usually modulated independently [1]. When such a modulation scheme is used to transmit data in a channel with frequency selective characteristics, the channel has to be estimated so that the channel response can be taken into account, i.e. equalized, when detecting the data from the received signal. A conventional approach is to dedicate some of the subcarriers as pilots, known to the receiver, which can be used to measure the channel response at the pilot frequencies. This is also the case in DVB-T. Thus in the following, it is assumed that pilots are available for channel estimation at the receiver. The channel response is assumed to be estimated for all the subcarriers.

In the case of linear channel and additive noise, the received symbol at carrier k, Y_k, is given by

$$Y_k = H_k X_k + D_k \tag{1}$$

where X_k is the transmitted symbol, H_k is the channel response and D_k is additive noise. When carrier k is a known pilot (i.e. value X_k is known at the receiver), the channel response can be calculated as

$$\tilde{H}_k = \frac{Y_k}{X_k} = H_k + \frac{D_k}{X_k} \tag{2}$$

It can be seen that in general $\tilde{H}_k \neq H_k$. Normally the channel responses, $\hat{H}_k$, for the data carrying subcarriers are found by interpolation [8] as follows

$$\hat{H}_k = \sum_{j=-L}^{L} c_j \tilde{H}_{k+j} \tag{3}$$

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where $\{c_j\}_{j=-L}^{L}$ are the interpolator coefficients and

$$\tilde{H}(k) = \begin{cases} H_k + \dfrac{D_k}{X_k} & k \text{ is a pilot} \\ 0 & \text{elsewhere} \end{cases}$$

It turns out that in some channel conditions even if the channel is estimated and equalized, the effect of additive noise and ICI destroys the performance of the communication system. This is why some extra measures are needed in the receiver to enhance the ability of the system to operate in these difficult channel conditions.

III. Combining Schemes

OFDM in mobile environment has been studied earlier in [7,9]. Previously it has been found, that maximal ratio diversity reception can improve BER performance significantly. Also it has been found out, that simple subcarrier selection combining (SC) diversity scheme utilizing instantaneous SNR criterion [7] could offer satisfactory diversity gain. In the following, the concept of subcarrier selection based on instantaneous SNR is clarified.

A. *Selection combining at subcarrier level*

By using (1), the power of received signal and noise samples are given by

$$\mathcal{E}\{|Y_k|^2\} = \mathcal{E}\{|H_k|^2\}\,\mathcal{E}\{|X_k|^2\} + \mathcal{E}\{|D_k|^2\} \quad (4)$$

where $\mathcal{E}\{\cdot\}$ refers to time average operation. Average SNR in the receiver at carrier k is therefore given by

$$\overline{\left(\frac{S}{N}\right)}_k = \frac{\mathcal{E}\{|H_k|^2\}\,\mathcal{E}\{|X_k|^2\}}{\mathcal{E}\{|D_k|^2\}} \quad (5)$$

On the other hand, instantaneous SNR in the receiver at carrier k can be defined by

$$\left(\frac{S}{N}\right)_k = \frac{|H_k|^2\,\mathcal{E}\{|X_k|^2\}}{\mathcal{E}\{|D_k|^2\}} \quad (6)$$

This measure takes only into account the instantaneous channel response value, H_k, while the actual instantaneous signal power $|X_k|^2$ and noise power $|D_k|^2$ are unknown and hence are approximated by their average values.

In the receiver, H_k, is approximated by $\hat{H}_k$. In the case of diversity reception, these channel responses are available from each of the I diversity branches. The task of the selection combiner is simply to choose the branch for which the instantaneous SNR is maximized for a given carrier k

$$i_k = \arg\max_i \left(\frac{S}{N}\right)_{k,i} \quad (7)$$

If the noise power of each of the diversity branches is the same, as often is the case, it is possible to modify the criterion as

$$i_k = \arg\max_i |\hat{H}_{k,i}| \quad (8)$$

where $\hat{H}_{k,i}$ is the channel response of ith diversity branch. Thus the output of SC is

$$\hat{X}_{k,sc} = \frac{Y_k}{\hat{H}_{k,i_k}}. \quad (9)$$

B. *Maximal ratio combining at subcarrier level*

As a reference an optimum combining method, i.e., maximal ratio combining (MRC) is used [9-12]. Here sample value of each branch is weighted according to signal power in that branch. It can be easily shown, that in OFDM case the output of MRC is given by

$$\hat{X}_{k,mr} = \frac{\sum_{i=1}^{I} Y_{k,i}\hat{H}^*_{k,i}}{\sum_{i=1}^{I} |\hat{H}_{k,i}|^2} \quad (10)$$

where it has been assumed that all the diversity branches have mutually independent channel responses.

It is worthwhile to note that each of the diversity schemes discussed here, can be implemented as shown in Figure 1. Here also some parts of error correction coding has been included, since in practical implementations they are typically incorporated.

IV. BER Evaluation of the Diversity Systems of DVB-T in a Mobile Environment

Evaluation of BER without error correction coding is straight-forward in presented diversity reception systems [7]. However, when error correction coding and possible interleaving are included in the BER estimation, the analysis becomes a laborious process and typically only upper limit for BER will be available. This is why the capabilities of diversity schemes in DVB-T [3] are compared by using simu-

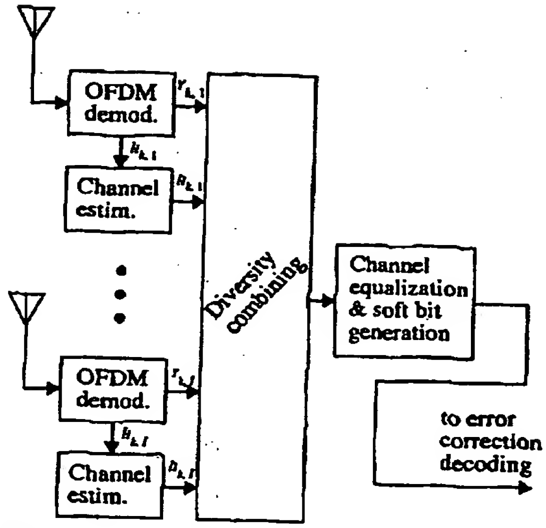

Fig.1 A generic diversity receiver.

lation. DVB-T was not originally intended to be used in mobile reception, but recently there has been some interest also towards this kind of service. At the time the specifications were designed, the special characteristics of mobile channel were not taken into account, making the mobile reception of DVB-T an interesting challenge.

The simulation parameters are as follows. DVB-T system with 8k mode using 16QAM, 2/3-rate convolutional coding and GI of 1/8 of useful symbol duration is applied. This set-up offers bit rate of 14.75 Mbit/s. BER was calculated after Viterbi decoder in the receiver. Multipath channel model is 6 path typical hilly terrain from COST 207 specifications [13] (Table 1). Symbol synchronization was assumed to be achieved in the simulation. This is a reasonable assumption in this kind of environment [14].

Table 1: 6-tap hilly terrain channel model

Tap	Delay µs	Power dB
1	0	0
2	0.1	-1.5
3	0.3	-4.5
4	0.5	-7.5
5	15	-8.0
6	17.2	-17.7

Doppler frequency was at first set to 60 Hz, which corresponds to receiver velocity of 75 to 138 km/h in the TV UHF band (@ 470 ... 862 MHz) depending on which channel is used. Matched Wiener filter [8] was used for frequency interpolation which consists of 21 taps ($L = 10$). In time direction simple linear interpolation with 7 taps was used. At first, cases where two or three independent diversity branches are used were simulated. Also a case where diversity is not used at all was simulated for comparative purposes. The results are shown in Figure 2. As can be seen, without diversity the performance is poor. In fact the required level for the system to operate properly, i.e. BER $2 \cdot 10^{-4}$ after Viterbi decoder, is not reached at all. However even the simplest diversity method, that is the two branch subcarrier selection combiner, provides such an improvement that only SNR of 12.6 dB is required for the target BER. By increasing third branch to diversity receiver, selection combiner gives approximately 1.6 dB more gain. As can be seen, this is approximately the same as with optimum maximal ratio combiner with two branches. If complexity is not an issue, three branch maximal ratio combiner can be used. The performance of this method is the best of all the presented methods as can be seen from the figure.

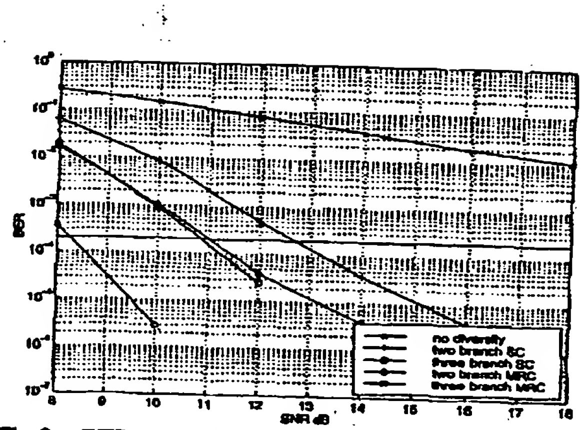

Fig.2 BER vs. SNR. Performances of different diversity schemes. Diversity branches are assumed to be independent. Doppler frequency is 60 Hz.

Next a case where Doppler frequency is increased from 60 Hz to 80 Hz was evaluated. The corresponding receiver velocity range is 100 to 184 km/h. Only the performances of subcarrier-based selection diversity schemes are simulated here. The results are shown in Figure 3. The target BER is reached with little bit higher SNR. In the case of two branch diversity about 4 dB more SNR is needed. The corresponding difference to the case of three branches is approximately 2.5 dB.

Subsequently BER floor [7,9] was evaluated in the case of two diversity branches. This is the BER

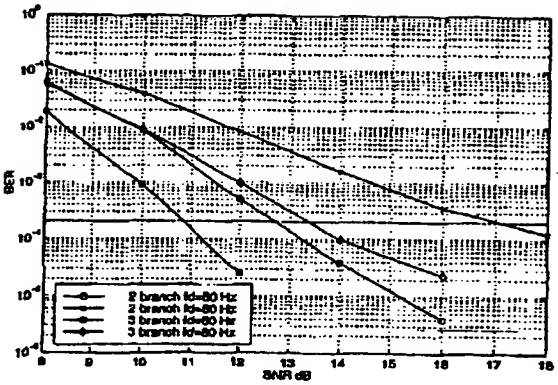

Fig.3 BER vs. SNR. Performance of subcarrier-based selection diversity scheme. Diversity branches are assumed to be independent.

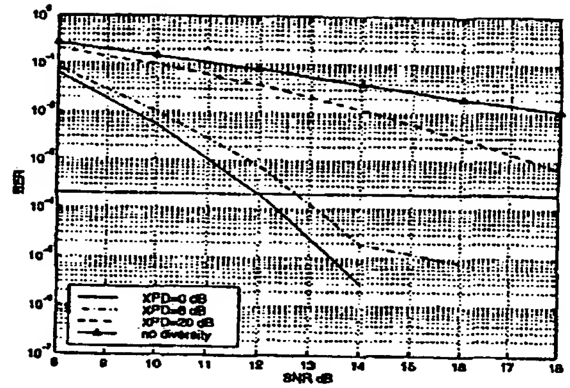

Fig.5 BER vs. SNR. Performance of subcarrier-based selection diversity scheme with different XPDs.

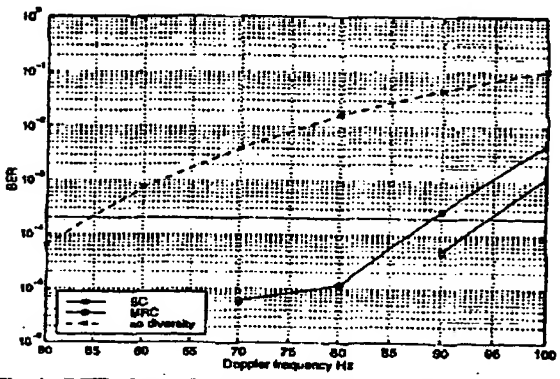

Fig.4 BER floor. Performances of different diversity schemes. Diversity branches are assumed to be independent.

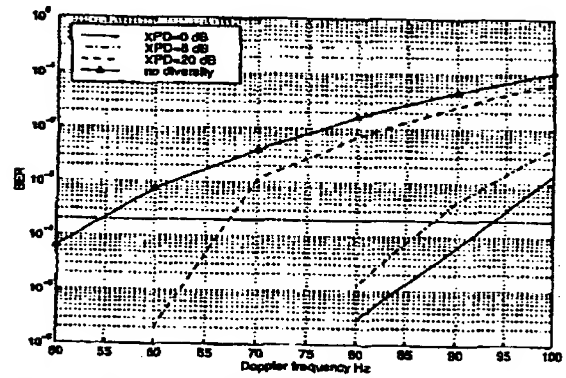

Fig.6 BER floor. Performance of selection combiner with different XPDs.

level, where BER saturates due to ICI when there is no additive noise at all. As illustrated in Figure 4, the target level is reached in this case when Doppler frequency is 90 Hz and 95 Hz for subcarrier selection combiner and maximal ratio combiner, respectively. Improvement to a case without diversity is about 40 Hz, i.e., mobile unit velocity can almost be doubled.

Finally more practical diversity scenario was tested. Here polarization diversity with SC was utilized. Depending on the Cross Polarization Discrimination (XPD) of the channel, different amount of independence can be achieved between two antennas with orthogonal polarizations. The antenna model used here was similar X-shaped dipole introduced in [15]. In this case it does not matter whether the transmitted signal is vertically or horizontally polarized. The results are valid for both cases. The multipath channel model is the same as before.

In Figure 5 the simulation results are shown for three different XPD values 0 dB, 6 dB and 20 dB. The case of 0 dB corresponds actually to a case where the signal components are mutually independent. Other values (6 dB and 20 dB) were selected to correspond Rayleigh-type and Line-of-sight -type channel conditions, respectively. The slight deviation of the curve representing a case when XPD=0 dB from the curve given in Figure 2 is due to simulation inaccuracy. However, the results are accurate enough for comparative purposes. As can be seen from Figure 5, when XPD=0 dB or when XPD=6 dB the performance loss is less than 1 dB at the reference level. Furthermore, it is shown that when XPD=20 dB, the loss is more than 6 dB. In practice, the XPD in mobile channels can be assumed to be around 6 dB [15] and hence the benefits resulting from the simple SC diversity are substantial also in practice.

The BER floor was determined using similar approach as earlier in this paper. Again the same

three XPDs were used in the evaluation. As illustrated in Figure 6, the performance difference between XPD=0 dB and XPD=6 dB is approximately 5 Hz. Again with XPD=20 dB the performance loss in considerable when compared to other XPDs. On the other hand there seems to be about 15 Hz improvement to a case without diversity. Since the Doppler frequency in this case is around 67 Hz, the dashed curve in Figure 5 will saturate below the reference level.

V. CONCLUSION

Selection combining and maximal ratio combining diversity schemes to be used with OFDM have been studied. Modification of conventional selection combining criterion, which is effective in OFDM, has yielded an substitute to maximal ratio combining method. It has been shown using simulation, that since its suboptimality, the performance is not as good as with MRC, but a lot better than without any diversity at all. The receiver structure is simple since no extra calculations are needed, only some relational operations.

The actual comparison between selection combining and maximal ratio combining has been carried out by numerical evaluation using DVB-T simulation model. It has been found out, that the selection combining can be a viable alternative when diversity is intended to be included in an OFDM system.

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